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ROCK CHIPS

ALBERTA GEOLOGICAL SURVEY

Fall/Winter 2001

Mission: Provide the geoscience information and expertise needed by government, industry and the public for earth resources stewardship and sustainable development.

Groundwater Chemistry in the Athabasca In Situ Oil Sands Area, Northeast Alberta

The primary purpose of the hydrochemical investigation in the Athabasca In Situ Oil Sands area (Figure 1) is to define predevelopment baseline conditions. Future chemical analyses can be compared to baseline to assess impacts energy development may have on groundwater resources. Additionally, chemical information provides a means of defining groundwater flow paths, calibrating water budget estimates,and predicting the impact of water disposal on aquifer quality, as well as defining the suitability of water for industrial, domestic, or agricultural applications.

Between summer 2000 and fall 2001, 41 samples were collected for chemical analysis. Samples were collected from wells completed in Quaternary drift aquifers, Quaternary/Tertiary buried valley aquifers, Cretaceous sands and Devonian carbonates. The samples were analyzed for major, minor and trace elements, organic acids, naturally occurring radionuclides, SiO_2, stable isotopes ($^{18}O/^{16}O$, $^{2}H/^{1}H$, $^{11}B/^{10}B$, $^{13}C/^{12}C$, $^{34}S/^{32}S$), radiogenic isotopes ($^{87}Sr/^{86}Sr$, ^{14}C) and field parameters (pH, ORP, conductivity, temperature, dissolved oxygen, alkalinity and density).

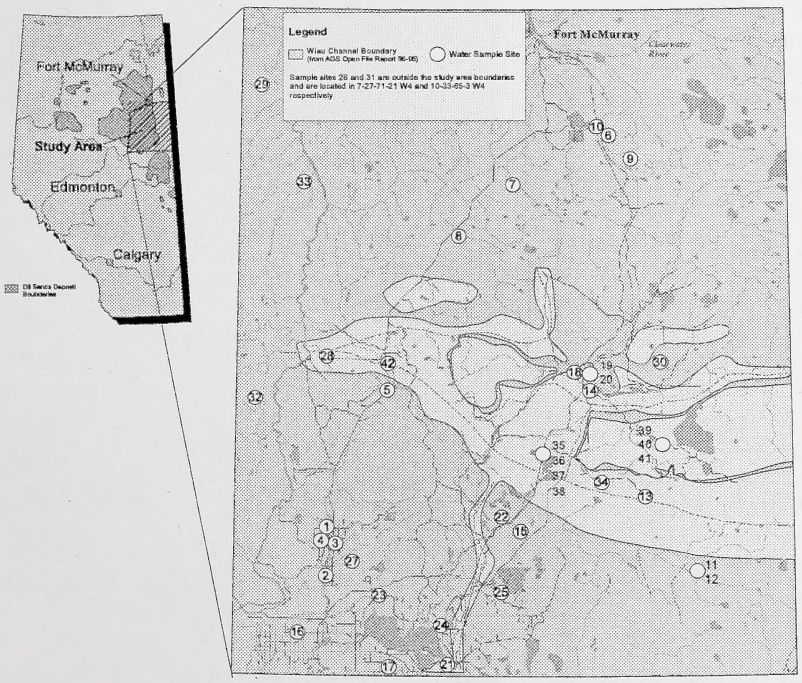
Fort McMurray
Study Area
Edmonton
Calgary
Legend
Wiau Channel Boundary (from AGS Open File Report 96-06)
Water Sample Site
Sample sites 26 and 31 are outside the study area boundaries and are located in 7-27-71-21 W4 and 10-33-65-3 W4 respectively
Fort McMurray
Clearwater River

Figure 1. Study area and sample locations.

A preliminary look at the chemical analyses suggests that the Quaternary and Quaternary/Tertiary aquifers have very similar waters. The total dissolved solids contents are below 600 mg/L and the dominant ions in solution are Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^{-} and SO_4^{2-}. The pH is approximately neutral. None of the major, minor, or trace element concentrations exceed Canadian drinking water guidelines for maximum acceptable concentrations and few exceed any aesthetic guidelines. Most isotope values are similar. There are differences, however. Total dissolved solids values increase with depth. Radiogenic isotope values vary.

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These results uncover a complicated mechanism of recharge and groundwater flow, as well as sediment-water chemical reactions along those flow paths. All of the above observations are consistent with previous scientific observations of how water chemistry changes. For example a Russian scientist, I.I. Chebotarev, identified that as water moves down and along a flow path, it increases in total dissolved solids and the relative ratios of the major ions change. As the water travels along the flow path, it interacts with minerals, dissolving some, precipitating others, undergoing cation exchange and mixing with other waters. What can be seen in the Quaternary and Late Tertiary aquifers is this process in action.

The area is covered by preglacial and glacial material, predominantly till, lacustrine clay and outwash or channel sand. Late Tertiary buried channel sand deposits are composed of quartz and chert derived from the Cordillera. Quaternary sand deposits contain igneous and metamorphic rock fragments derived from the Canadian Shield, in addition to quartz and chert. Lacustrine clays are dominantly composed of smectite-rich and illite-rich clays. The tills contain varying quantities of sand, silt and clay, along with sedimentary, igneous and metamorphic clasts up to boulder size and abundant pulverized dolomite and calcite. Water flows downward and laterally along the flow path, passing through these layers of till, clay and sand. Water reacts with these materials, first dissolving the calcite and dolomite, giving the water its characteristic Ca^{2+}-Mg^{2+}-HCO_3^- composition. As the water continues along the flow path, cation exchange occurs on the clays, removing Ca and Mg and replacing them with Na and K. Sulphide minerals in the till and clay are oxidized by the infiltrating water, adding SO_4^{2-}. The reaction to generate SO_4^{2-} from S^{2-} releases acid, accelerating the dissolution of carbonate minerals. As the concentrations of Ca^{2+} and HCO_3^- increase, calcite begins to precipitate. The water shifts from a Ca^{2+}-Mg^{2+}-HCO_3^- water to a Na^+-HCO_3-SO_4^{2-} water.

The processes the water undergoes are known, but what is the source of the water within these aquifers? Is it present-day meteoric water, or seawater? Is it thousands of years old, or possibly tens of thousands of years old? To answer these questions, stable and radiogenic isotopes are used. What are isotopes? The answer to that question begins at the atomic level.

An atom is defined by the number of protons and neutrons that make up its nucleus. The number of

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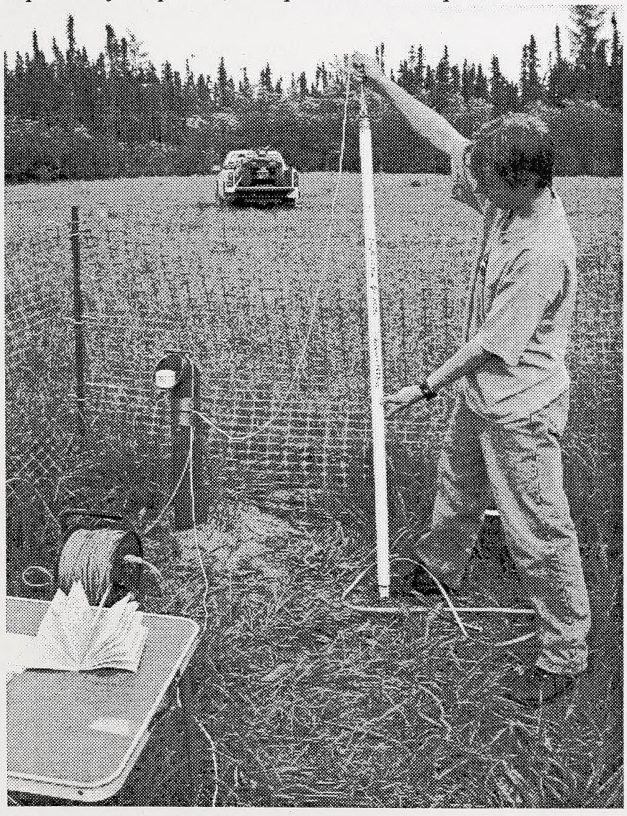
protons defines the element and the number of neutrons defines the isotope of that element. The sum of the neutrons and protons gives the atomic weight. Stable isotopes are naturally occurring, naturally abundant atoms of an element. For example, most oxygen atoms possess 8 protons and 8 neutrons for an atomic weight of 16, hence ^{16}O. However, a small percentage of oxygen atoms has 8 protons and 10 neutrons for an atomic weight of 18 and is denoted ^{18}O. Radiogenic isotopes, on the other hand, are the daughter products of nuclear decay and may or may not decay to another daughter product.

For stable isotopes, the ratio of the two most abundant isotopes of an element is measured and compared to a standard. The ratio is then expressed in the permil notation

$$\delta^{18}O = [(^{18}O/^{16}O)_{sample}/(^{18}O/^{16}O)_{standard} - 1] \times 1000‰$$

A value of +10 permil compared to the standard indicates that the sample has 10 permil, or 1 per cent more ^{18}O than the standard, or is enriched by 10 permil. Conversely, a sample with a –10 permil result would be depleted by 10 permil, or 1 per cent as compared to the standard. As waters pass through the hydrologic cycle, the ratio of the isotopes can change. These changes are the result of physical, chemical, or biological processes. By comparing the results obtained from the analyses with published results, the source of water and processes it has undergone can be determined.



Hydraulic testing with a piezometer.

Radiogenic isotopes are reported a number of different ways. They can be reported as a ratio of the decay product to the stable isotope; for example, $^{87}Sr/^{86}Sr$. They can be reported as percent modern carbon (specifically for ^{14}C) or as concentration or disintegrations per volume, as with many radionuclides. Just as with stable isotopes, radiogenic isotope ratios and concentrations can be affected by physical and chemical processes. Comparison of results to published values can help to define the processes and sources of water.

When the isotope values are examined, some interesting patterns come to light.

1) The $\delta^{18}O$ and $\delta^{2}H$ values for the sampled wells are very similar to the values for modern-day precipitation. This suggests that water flowing through the aquifers has entered the system after the last glaciation or since about 11 000 years ago. The ^{14}C dates for the water samples (still in preparation) will better define that date. In addition, since samples were taken from various depths within the aquifer systems, the residence times and flow characteristics might also be better defined.

2) Water that has equilibrated with different types of rock matrices (carbonates, igneous rocks, metamorphic rocks, etc.), will have different $^{87}Sr/^{86}Sr$ ratios. Because the glacial materials the groundwater has passed through contain various rock types, $^{87}Sr/^{86}Sr$ values vary greatly from sample to sample. Further examination of the Sr data may reveal a pattern in the Sr ratios, yielding more detailed information on water source.

3) The $\delta^{34}S$ values suggest the sulphur in the system could be originating from a number of sources. The most likely sources include petroleum and coal, sulphide minerals and shales. This is consistent with the make-up of the glacial tills the groundwater passes through. One of the sulphur isotope samples taken from the buried channel aquifer has a value for $\delta^{34}S$ sulphate which suggests bacterial cycling of sulphur.

4) Preliminary inspection for $\delta^{11}B$ suggest that groundwater in these aquifers may be sourced from marine carbonates or granitic rocks. This is consistent with the composition of the tills in the area.

5) The $\delta^{13}C$ of the dissolved inorganic carbon in groundwater reflects the mixing process between soil CO_2 and dissolved carbonate. A change in the relative abundance of either of these components will affect the overall $\delta^{13}C$ value. The results for most samples are consistent with mixing of C from soil CO_2, with dissolved carbonate. The sample that had the anomalous sulphur isotope value from the buried channel aquifer also has an anomalous $\delta^{13}C$ value. The $\delta^{13}C$ value suggests that dissolved carbonate is not mixing with soil CO_2. If this is true, then water moving through the till is not dissolving carbonate in the same manner as elsewhere. Since all the till in the area contain carbonates, this could mean that this aquifer may have a different recharge mechanism that bypasses the carbonate-rich tills.

From a hydrologic point of view (Figure 2), a summary of the hydrogeochemical processes at work in the Athabasca In Situ Oil Sands area would include recharge by meteoric water and subsequent water rock interactions, resulting in the observed water chemistry. More specifically, the following can be said:

1) Recharge of the aquifers by meteoric water with an isotopic signature consistent with our present-day climactic values.

2) Dissolution of carbonate and sulphide minerals, with subsequent carbonate mineral precipitation further along the flow path. An exception may exist in the case of the buried channel aquifer where recharge may be bypassing carbonate rich till.

3) Cation exchange, along the flow path of Ca and Mg for Na and K occurs on the smectite and illite-rich clays, with subsequent changes in the water type.

4) Isotopic results suggest that groundwater is reacting with carbonates, shales, petroleum and coal, igneous rocks and pyrite. This is consistent with till lithology, field observations and chemical results.

The continued analysis of the data should provide additional insight into this complicated system.

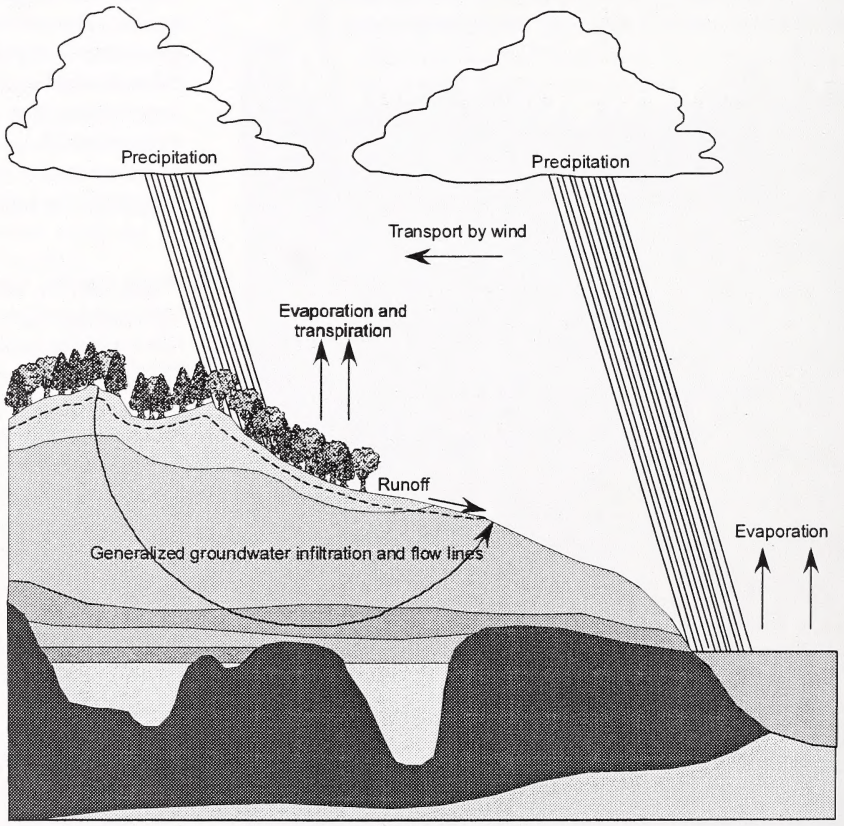


Figure 2. Summary of groundwater flow.

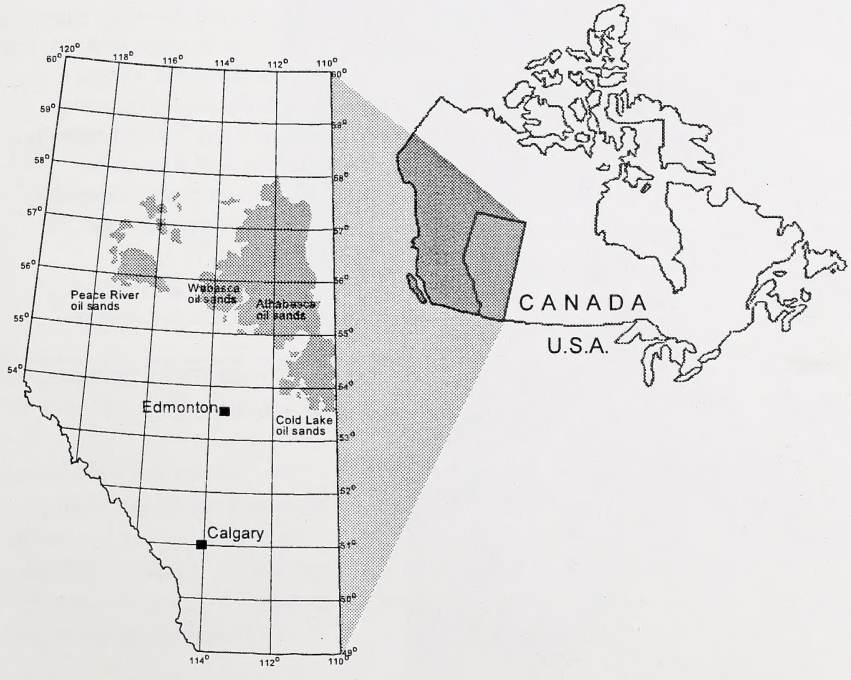
Field Guide for Facies Characterization of the Athabasca Oil Sands Released

A Comprehensive Field Guide for Facies Characterization of the Athabsca Oil Sands, Northeast Alberta was released for sale this past summer. The report, SPE 13, is available as a 21.4 MB PDF document for $20.00 from the Alberta Geological Survey Information Sales office.

The study, initiated May 1, 1997, was designed to perform regional facies work on the Athabasca oil sands deposit of northeast Alberta, focusing on outcrops as well as selected subsurface core studies of the McMurray Formation. The aim of this project was to characterize the oil sands of the Athabasca deposit at a facies scale of resolution that would be used as a basis for ongoing regional assessment of the oil sands deposit. This study was very successful in combining detailed outcrop and subsurface results that led to the development of three facies models for the McMurray succession. It represents an important step forward in our understanding of the Athabasca oil sands deposit.

The report is intended to be a comprehensive catalogue of selected major outcrops that were measured during regional facies work on the McMurray Formation, compiling fieldwork over four seasons (1997-2000) in the Athabasca River drainage area. Emphasis of the study was on the geologic setting, sedimentology and facies analysis of the oil sands deposits. The study included detailed work on 78 outcrop sections, about 150 cores and over 6000 regional geophysical well-log picks. All of the outcrop sections occur along the Athabasca-Clearwater river drainage networks. In conjunction with this regional facies work, detailed palynological and biostratigraphic analyses were completed, mainly in the Steepbank River area and along the southern margin of the Bitumount Basin. Other in-depth work included outcrop-geophysical log correlation and synthetic seismic modelling of outcrops in the Steepbank River, with comparisons with subsurface seismic results in the Clarke Creek area.

The present special report complements two previous Earth Sciences Reports. The first, ESR 2000-05, *Historical Overview of the Fort McMurray Area and Oil Sands Industry in Northeast Alberta,* contains an overview of the exploration and historical development of the Fort McMurray area, with emphasis on development of the oil sands industry in Alberta. The second report, *An Atlas of Lithofacies of the McMurray Formation*, ESR 2000-07, includes a comprehensive facies classification that incorporates both outcrop and subsurface examples. We hope that these publications will aid other workers dealing with the complex issues concerning the development of the vast Athabasca oil sands deposits and will serve as valuable sources of information for government, industry and general public stakeholders.



Location map of the Athabasca, Cold Lake, Peace River and Wabasca oil sands deposits.

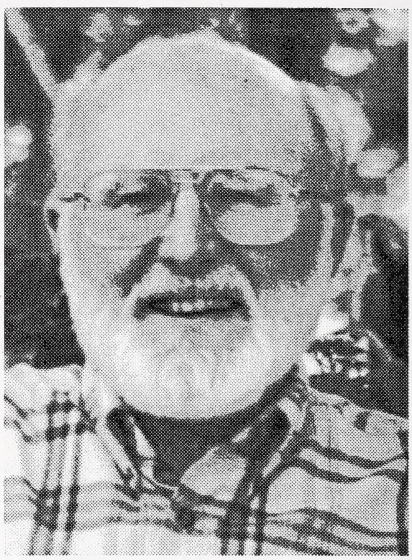
John Godfrey, Geologist, Colleague and Friend

John D. Godfrey, former geologist of the Alberta Geological Survey passed away peacefully in his home in Edmonton on October 6, 2001. He was 72.

John was born in the mining village of Pilsley near Chesterfield, England, the eldest of three sons. He completed his secondary schooling at Tupton Hall Grammar School and received the Bachelor of Science degree from the University of Nottingham. Sailing from Southampton on September 22, 1950, on a steamer bound for the Statue of Liberty, John proceeded to the University of Chicago, where he completed the Doctorate of Philosophy in Geophysical Sciences.

John continued north and west to the University of Alberta (1955), where, as a teacher, he met and worked with his future wife, Doreen. They were married on May 5, 1956 and over the next six years became the proud parents of three sons.

In 1956, John joined the Alberta Research Council and realized his passion for field geology. He traversed the Precambrian Shield and the northeast corner of Alberta by foot, canoe, float plane and helicopter, producing his beloved maps and reports. He retired from the Alberta Research Council in 1985.



His soccer skills were legendary and he competed for a position on the U.S. National Soccer team in the 1950s. Over the years John actively participated in his community as a coach for various swimming and soccer teams.

After his retirement in 1985, John's professional focus turned to geological consulting and the formulation of Godfrey Tours. John planned and hosted over 40 tours, which were based upon geological, natural and cultural history. The majority of these tours were international. He was an active member of APEGGA and the Faculty Club of the University of Alberta.

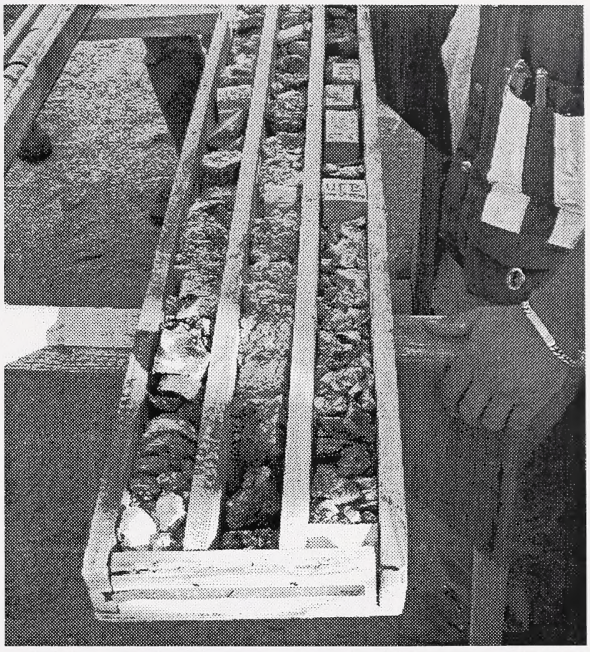
John's inexhaustible energy, vibrance, commitment to work, brilliance as a teacher and capacity for friendship will forever be remembered and greatly missed by his family, collegues, friends and students.

Athabasca Uranium Extech IV

Extech IV, a multidisciplinary study on uranium in the Athabasca Group, began in April 2000. The project is scheduled to end, March 2003. The study involves representatives from the Geological Survey of Canada, Saskatchewan Energy and Mines, Alberta Geological Survey, two industry partners (Cogema, Cameco), University of Saskatchewan, Saskatchewan Research Council, Laurentian University and University of Alberta.

Alberta has about 15 per cent of the Athabasca Basin, while approximately 85 per cent of the Basin resides in Saskatchewan.The lack of information on this area is discouraging exploration in Alberta. Through this project, Alberta will obtain a large amount of information from that already found in Saskatchewan.

The primary objectives of Alberta's contribution to Extech IV are to get a better understanding of the Athabasca Group, the underlying Precambrian basement and overlying Quaternary and surficial geology in Alberta. The resulting data will encourage renewed uranium exploration in Alberta.



High grade uranium core from Maybelle River, Alberta.

McLean Lake B pit, Northern Saskatchewan

Story contact information

The following AGS staff may be contacted for further information on their articles:

Groundwater Chemistry	Tony Lemay	(780) 422-2619
Field Guide for Facies Characterization	Mike Berhane	(780) 427-0045
Athabasca Uranium Extech IV	Reg Olson	(780) 427-1741
Quaternary Geology...Wapiti Map Area	John Pawlowicz	(780) 427-1929
Regional Evaluation of Coal-Bed Methane	Willem Langenberg	(780) 427-0809
Surficial Mapping Peerless Lake	Mark Fenton	(780) 427-1764

They may also be contacted via e-mail by entering the author's <first name.last name@gov.ab.ca>

Quaternary Geology and Till Geochemistry, Wapiti Map Area

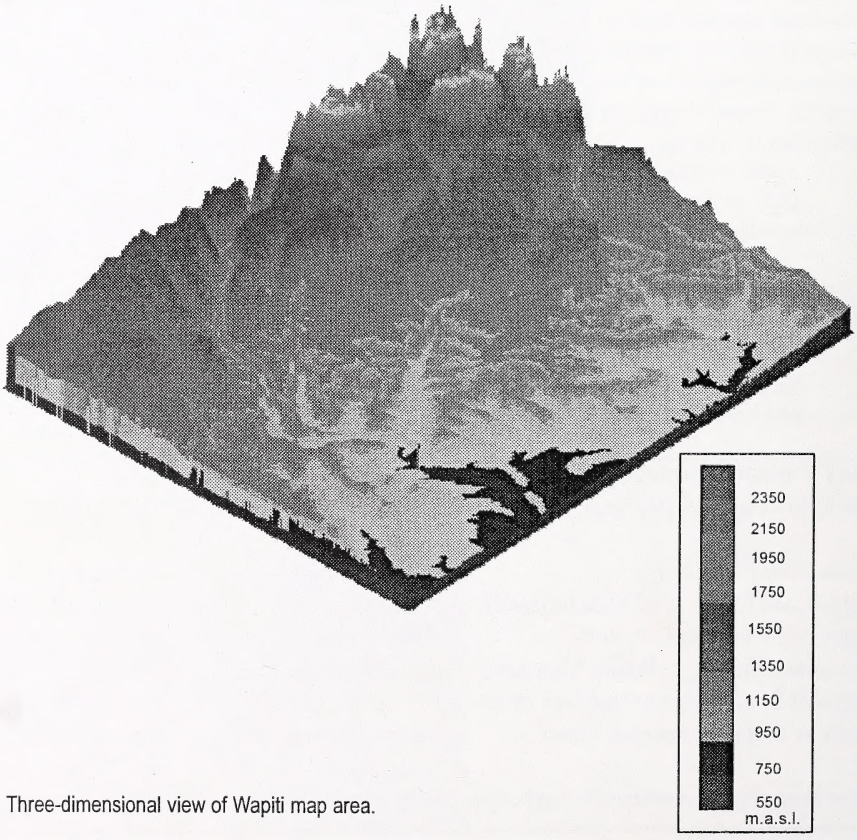
This report, released in the summer as ESR 2000-02, provides the current data and interpretations concerning the surficial geology and till geochemistry of the Wapiti map area (NTS 83L). Work on the project was suspended during the second year due to reprioritizing of staff effort.

The area encompasses the transition zone from the Interior Plains to the Eastern Cordillera, with elevation rising from about 525 m (1720 ft) in the northeast to 2455 m (8050 ft) in the southwest. Four physiographic regions can be defined: the Wapiti Plains, the Alberta Plateau Benchlands, the Rocky Mountain Foothills and the Rocky Mountains.

The surficial geology is shown on a 1:250 000 scale map, compiled by Andriashek (1983) based on unpublished work by A. Twardy and L. Bayrock. The main surficial materials are till, glaciolacustrine sediment, weathered bedrock and, to a lesser extent, glaciofluvial sediment. The till includes units deposited by Laurentide (Continental), Cordilleran and Rocky Mountain ice sheets.

The ice-flow direction, from the Rocky Mountain, Cordilleran and Laurentide glacial centres and the relationships between the various lobes are poorly understood. Field examination of the pebble to boulder fraction indicates that the till units are characterized by 1) clasts of green metaconglomerate and low-grade greenish grey schist, plus granite and other igneous rocks (mixed Laurentide and Cordilleran sources), in the northwest;
2) clasts of grey carbonate (Rocky Mountain or Cordilleran source) in the west and southwest;
3) mainly quartzite and igneous (primarily granite) clasts (Laurentide source) in the east;
4) abundant well-rounded quartzite clasts, incorporated from the underlying Tertiary gravel deposits, in parts of the centre and south;
5) boulders of low-grade schist (?earlier Cordilleran source) at three sites in the south-central part of the area; and
6) a boulder of low-grade, grey metamorphic rock, perhaps phyllite, in the southeast (source uncertain).

The majority of the samples were collected from areas accessible by road; a few were obtained using a helicopter to reach less accessible sites. Most of the samples collected are from till. Others are from bedrock, lacustrine, colluvial, or fluvial units. At each site, a 2–3 kg sample was collected from below the top of the C soil horizon (at a depth of about 2 m) for geochemical and carbonate analysis of the less than 0.063 mm fraction and texture analysis of the less than 2 mm fraction. Field data recorded at each site included information on the general sampling environment and observations on the colour, texture, moisture content and mineralogy of the till.



Three-dimensional view of Wapiti map area.

Regional Evaluation of the Coal-Bed Methane Potential of the Foothills/Mountains of Alberta

Conventional gas reserves in Alberta are predicted to decline in the next decade and, consequently, the government and industry are showing a renewed interest in exploring for coal-bed methane (CBM). The AGS embarked on a project beginning April 1, 2000 to evaluate the regional potential of CBM production from Foothills/Mountain coal in Alberta. The areas of best CBM potential in the Foothills will be identified. The project is scheduled to finish at the end of March 2002.

The project will proceed in the following manner:

- establish the volume of Foothills/Mountain coal based on coal thickness and areas underlain by specific coal zones
- determine if the coal zone is less than 2500 m or deep
- establish the rank of the various coal zones
- estimate the gas content of the various coal zones

An EUB/AGS Earth Sciences report, ESR 2001-19, was released in October on this project. Estimates of the gas content of coal to a depth of 2500 m in Alberta's Foothills/Mountains indicate a volume of 1.5 x 1012 m^3 (about 53 Tcf) CBM in place.

Cardinal River Mine, AN Pit.

Surficial Mapping in the Peerless Lake Map Sheet (NTS 84B)

Exploration continues to be active in northern Alberta for both mineral targets such as kimberlites and uranium, as well as the shallow gas energy targets. These activities benefit significantly from information on surficial geology, Quaternary stratigraphy, drift thickness, bedrock topography, glacial history and dispersal patterns.

This year marks the second step in a decade-long plan by the Alberta Geological Survey to complete the surficial mapping of northern Alberta.

The field work was done during July and completed investigations of previous years. Progress was made both on the technical and scientific fronts. The efficiency of field data handling was greatly improved by acquiring, for the first time, the hardware and software to create an integrated field office. The capability of the Palm Pilots, introduced last year to take surficial data, was increased by the improvement of the surficial geology form and the creation of four new geochemistry forms for recording data related to the sampling of till, soils, peat and twigs.

This year the Palms were complemented by having additional hardware (laptops, backup facilities, printer and digital cameras). This improved operational efficiency and effectiveness in many ways. We were able to get up-to-date sample maps each evening as the data were uploaded, moved into ArcView and both displayed and printed. Each day digital photos were transferred to the laptops, viewed and either labelled or discarded - a vast improvement over having to wait for photographs to be developed at the end of the field season. These cameras also allowed written field notes to be transformed each evening, into digital form for storage and backup in the laptops and zip disks. The ability to print selected parts of Landsat 7 satellite images each evening for an up-to-date "access map" for the next day's travel proved of great help. Energy and forestry development have made traditional paper base maps out of date.

The scientific highlights include the discovery of thin till < 2 m, (Figure 1) overlying the Mesozoic bedrock in a portion of the Buffalo Head Hills, which was previously thought to have been covered by at least 5 m of till. This till appears to form a veneer over small bedrock uplands that look to form the remains of an eroded landscape. A carbonate boulder containing pyrite was discovered on the Bad Rapids on the Wabasca River (Figure 2). The collection of till samples on a grid over a glacial dispersal train in hummocky stagnant ice terrain revealed that small sand and gravel lenses were more abundant than had been expected. About 15 per cent of the hand auger holes intersected 10 to 30 cm of glaciofluvial sediment in the upper 2 m. A preliminary test of the use of portable conductivity and ph meters to help distinguish between the various wetlands (bogs, fens, etc.) proved successful. Samples were taken from the surface and subsurface using peat samples.

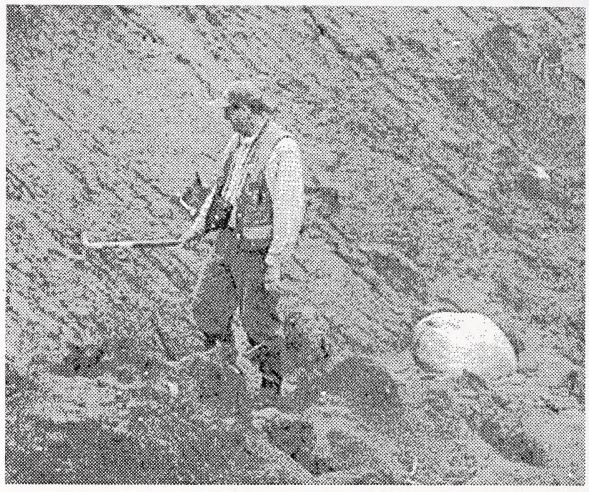


Figure 1. Sampling of thin till in the Buffalo Head Hills area.

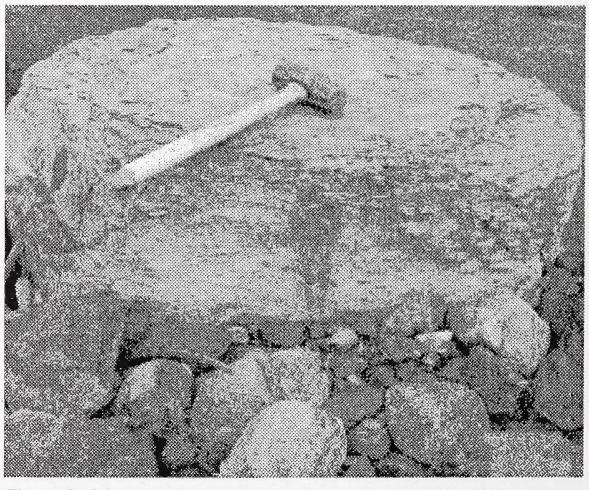


Figure 2. Carbonate glacial erratic containing sulphides, Bad Rapids, Wabasca River.

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The following groundwater reports are sold on behalf of the Prairie Farm Rehabilitation Administration (PFRA). Any questions regarding these reports should be directed to Hydrogeological Consultants Limited at 1-800-661-7972.

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SPE 27 County of Vermillion River No.24, Regional Groundwater Assessment. 523 MB. 2001. $20.00

SPE 28 County of Thorhild No.7, Regional Groundwater Assessment. 131 MB. 2001. $20.00

SPE 29 Strathcona County, Regional Groundwater Assessment. 193 MB. 2001. $20.00

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SPE 30 County of Stettler No. 6, Regional Groundwater Assessment. 241 MB. 2001. $20.00

SPE 31 Starland County, Regional Groundwater Assessment. 132 MB. 2001. $20.00

SPE 32 County of St. Paul No. 19, Regional Groundwater Assessment. 219 MB. 2001. $20.00

SPE 33 Special Areas 2, 3 and 4 and M.D. of Acadia, Regional Groundwater Assessment. 600 MB. 2001. $20.00

SPE 35 M.D. of Provost No. 52, Regional Groundwater Assessment. 366 MB. 2001. $20.00

SPE 36 Parkland County, Regional Groundwater Assessment. 198 MB. 2001. $20.00

SPE 37 County of Paintearth No. 18, Regional Groundwater Assessment. 223 MB. 2001. $20.00

SPE 39 County of Minburn No. 27, Regional Groundwater Assessment. 231 MB. 2001. $20.00

SPE 40 Leduc County, Regional Groundwater Assessment. 263 MB. 2001. $20.00

SPE 41 County of Lacombe No. 30, Regional Groundwater Assessment. 164 MB. 2001. $20.00

SPE 42 Lacombe County, Regional Groundwater Assessment. 269 MB. 2001. $20.00

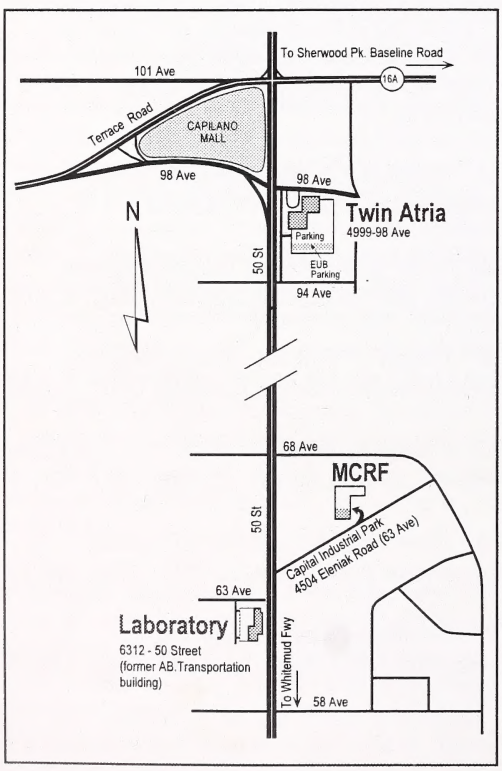
SPE 43 Lac Ste. Anne County, Regional Groundwater Assessment. 226 MB. 2001. $20.00

SPE 44 Flagstaff County, Regional Groundwater Assessment. 238 MB. 2001. $20.00

SPE 45 M.D. of Brazeau No. 77, Regional Groundwater Assessment. 275 MB. 2001. $20.00

SPE 46 County of Beaver No. 9, Regional Groundwater Assessment. 162 MB. 2001. $20.00

SPE 47 County of Athabasca No. 12, Regional Groundwater Assessment. 419 MB. 2001. $20.00



AGS Locations

The main office of the Alberta Geological Survey is located at

4th Floor, Twin Atria Building
4999 - 98th Avenue
Edmonton, Alberta
Canada T6B 2X3
Phone: (780) 422-1927
(780) 422-3767 Information Sales
Fax: (780) 422-1459
(780) 422-1918 Information Sales

The Alberta Geological Survey Library is located at the address above and may be contacted at

Phone: (780) 427-4663
e-mail: <EUB.AGS-Library@gov.ab.ca>

Our Mineral Core Research Facility (MCRF) is located at

4504 Eleniak Road
Edmonton, Alberta

For information on the MCRF or to book a visit, contact Rob Natyshen by phone at (780) 466-1779 or by e-mail at <Rob.Natyshen@gov.ab.ca>